

# FABRICATION AND CHARACTERIZATION OF PLANAR INTEGRATED SCHOTTKY DEVICES FOR VERY HIGH FREQUENCY MIXERS

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## ABSTRACT

Many millimeter-wave mixers and frequency multipliers today still employ a whisker contacted Schottky diode as the nonlinear device. In order to reduce the risk and assembly cost associated with these critical receiver components for NASA's present and future space missions, the authors have developed a novel fabrication procedure that integrates a planar Schottky diode with the mixer circuitry thus greatly simplifying the assembly and testing of the diode circuits. The process and DC results obtained so far will be discussed along with some preliminary RF results at 200 GHz.

## INTRODUCTION

Present generation NASA space-borne instruments employing millimeter-wave radiometers, such as the Microwave Limb Sounder (MLS) operating on the Upper Atmosphere Research Space Satellite (UARS), use whisker contacted Schottky diodes in both the mixer and frequency multiplier circuitry. However, the delicate nature of the whisker contact decreases the reliability of the instrument. Recently, it has been shown that, at least up to 350 GHz planar integrated diodes perform as well as whisker contacted diodes [1,2,3] and it is believed that the next generation of space-borne instruments will utilize this advancement in technology. Though mounting of the planar diode chip in the mixer circuit is not as labor intensive as the contacting of a whisker diode, it is still not a trivial task. The planar diode chips are typically 150x50 microns and require some expertise in order to place them correctly in a given circuit.

In order to alleviate this problem we have suggested integrating the Schottky device with additional mixer filter circuitry which makes it easier to handle as the device is now a part of a much larger structure. Unfortunately, GaAs does not lend itself as readily to typical waveguide mixer circuitry and generally quartz is preferred. In this paper we discuss the procedure that has been developed to combine the planar GaAs Schottky diode with the mixer quartz filter circuitry thus resulting in a

mechanically robust, easy to handle structure. Initial DC and RF results will also be discussed.

## PROCESS DEVELOPMENT

At higher frequencies it is believed that losses due to the GaAs substrate can degrade performance. The process that was designed to fabricate these Schottky diodes removes all of the GaAs on the chip except under the Schottky and ohmic contacts. It has been demonstrated at the University of Virginia that thinned substrate devices can be transplanted on to quartz using UV cured optical cement [4]. However, that exact process can not be replicated in our case since the heavily doped layer of GaAs extending all the way in the waveguide channel will be highly detrimental to the circuit's RF performance. In our method, once the devices and the associate circuitry is fabricated on the GaAs, the wafer is mounted upside down on the quartz plate with a UV curable optical cement. Once the GaAs substrate has been completely removed the mixer filter structures, which include the planar Schottky diode can be diced and tested. Though we believe that this process is portable to other planar devices thus far we have only investigated it for the fabrication of the 220,440, and 640 GHz subharmonically pumped waveguide mixers. This mixer uses a split block waveguide circuit with a single quartz insert. The circuitry that is integrated with the planar diode consists of two in-line hammerhead filters, signal and LO coupling probes, and a DC return for diode biasing and monitoring. Details of the block and the filter structures are presented in [2]. The salient steps of the fabrication process are detailed below.

1. 200-400 nm of Silicon-dioxide is deposited via an Electron Cyclotron Resonance(ECR) machine, Fig. 1(a).
2. Holes are opened lithographically in the oxide and the epilayer is etched until contact to the n + layer is made. The same mask is used to etch the oxide and the GaAs and then lift-off the ohmic contact metal, Fig. 1(b).
3. The Schottky metal(Ti/Pt/Au) is evaporated, Fig. 1(c). Optical lithography is used for anode diameters of 1.0 micron or more. At 600 GHz, submicron anodes are required and direct-write E-beam will be used.
4. The filter pattern is deposited as Cr/Au including the anode contact fingers on the planar Schottky diodes which are in an antiparallel configuration, Fig. 1 (d). The metal is electroplated up with gold to at least three skin depths at the desired operating frequency.

5. The devices are electrically isolated by etching a channel under the anode fingers through to the GaAs buffer layer. The etchant used is sensitive to the crystal direction and undercuts the fingers without etching the GaAs surrounding the Schottky anode, Fig. 1 (e). This technology was developed at the University of Virginia and is discussed in [4].

6. The processed GaAs wafer is bonded device side down on the quartz plate which at 200 GHz is 150 micron thick. The wafer is held via a commercially available UV cured optical adhesive , Fig. 1 (f).

7. The semiconductor substrate is removed by first lapping it down mechanically to about 50-100 micron and then etching it in a selective etch which stops when the AlGaAs layer is exposed, Fig.1 (g).

8. The remaining GaAs on the backside of the device is completely removed, except in the area around the Schottky diode. This is accomplished using reactive ion etching. It is important to use a dry etch at this point in order to avoid severe undercut and a drastic reduction in the yield, Fig. 1(h).

Once the GaAs from the back is completely removed the filter structures can be diced and placed in the waveguide block for testing. Fig. 2 shows the completed device both (a) the metal side, and (b) the quartz side. Fig. 3 shows a SEM of a portion of the filter used at 200 GHz.

## RESULTS

The diode structure that has been designed and fabricated has a 100 nm top GaAs epilayer doped at  $4.0 \times 10^{17} \text{ cm}^{-3}$  followed by a 3.0 micron thick heavily doped ( $2 \times 10^{18} \text{ cm}^{-3}$ ) GaAs layer. The buffer layer is undoped GaAs and 700 nm thick. Finally the etch stop layer is AlGaAs (Al = 55%) and is 400 nm thick. The substrate is semi-insulating. The diodes produced from this layer structure have typically 1 micron diameter anodes with an ideality factor of 1.4, saturation current of  $5 \times 10^{-14} \text{ A}$ , series resistance of 13-16 ohms and a barrier height of approximately 1.05 eV.

With discrete GaAs devices of similar layer structures we have obtained single sideband noise temperatures of less than 2000 K in our waveguide mixer block [2]. However, for the devices already integrated with the filters the best results to date have been a noise temperature of 10,000 K. Moreover, the LO power required to drive the unbiased diode pair is much larger (6-8 times) than the power required for the discrete devices. We believe the poor performance of the integrated devices is

caused by two as yet unresolved fabrication problems. First, the integrated structures have exceptionally high pad-to-pad capacitance (larger than 30 fF). This accounts for the poor LO coupling and much of the high noise temperature. Second, the diode ideality factor and saturation current are higher than expected (the better discrete diodes have an ideality factor of 1.2 and saturation current of less than 1. E-15 A). Efforts are currently underway to correct these shortcomings.

## CONCLUSIONS

A fabrication method has been discussed and demonstrated that integrates a planar air-bridge-type Schottky-diode pair with associated quartz mixer circuitry. This procedure will allow diode circuitry to be used at frequencies too high to allow a separate diode chip to be used. The Schottky diodes obtained via this process have so far had poor DC characteristics and large parasitic capacitance which have limited the RF performance. Efforts are underway to resolve these problems so better RF performance can be obtained.

## REFERENCES

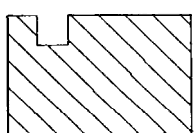
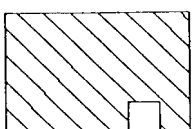
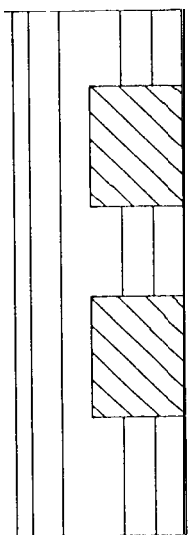
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2. P. Siegel, R. Dengler, I. Mehdi, J. Oswald, W. Bishop, T. Crowe, and R. Mattauch, "Measurements on a 215 GHz Subharmonically Pumped Waveguide Mixer using Planar back-to-back Air Bridge Schottky Diodes," to be published in IEEE-MTT.
3. T. Newman, W. L. Bishop, K. T. Ng, S. Weinreb, "A Novel Planar Diode Mixer for Submillimeter-Wave Applications," IEEE-MTT vol. 39, no. 12, pp. 1964-1971, December 1991.
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Fig. 1. Process flowchart

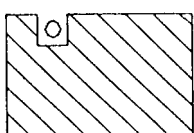
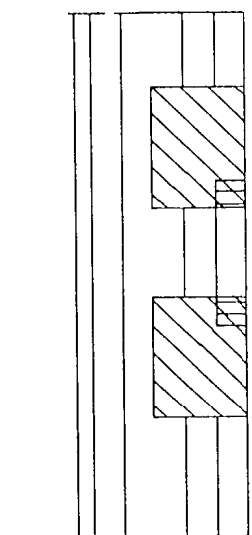
$\text{SiO}_2$   
 GaAs,  $n^-$   
 GaAs,  $n^+$   
 GaAs buffer  
 etch stop

SUBSTRATE, Si

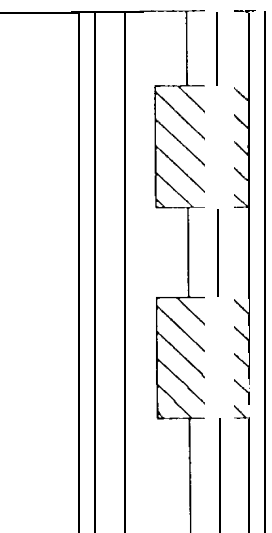
(a) Oxide deposition



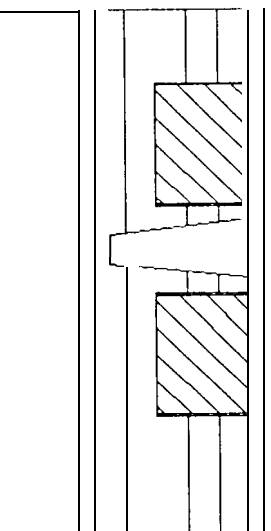
(b) ohmic metalization



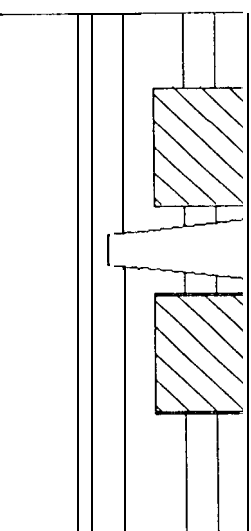
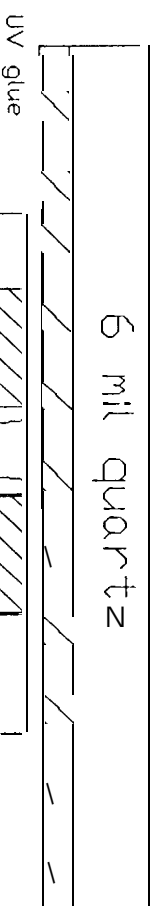
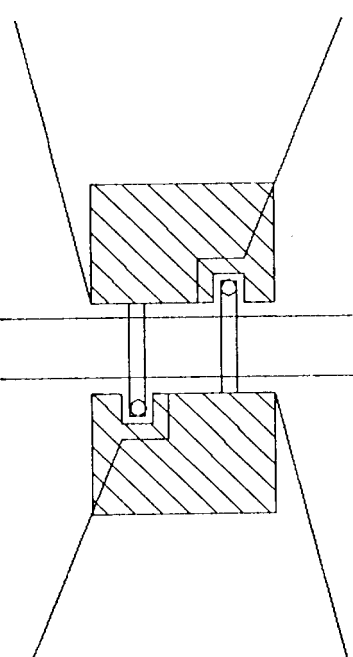
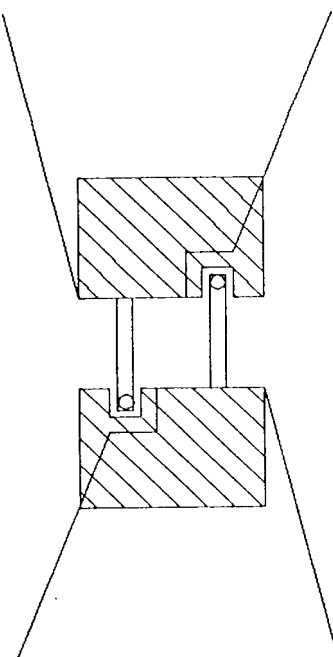
(c) Schottky metalization



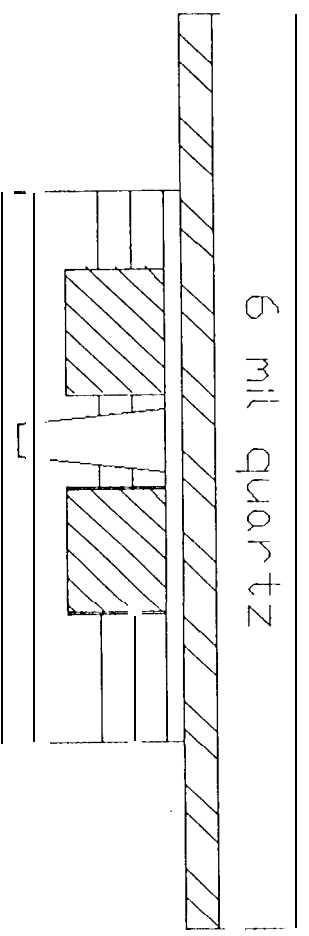
(c) Filter metallization



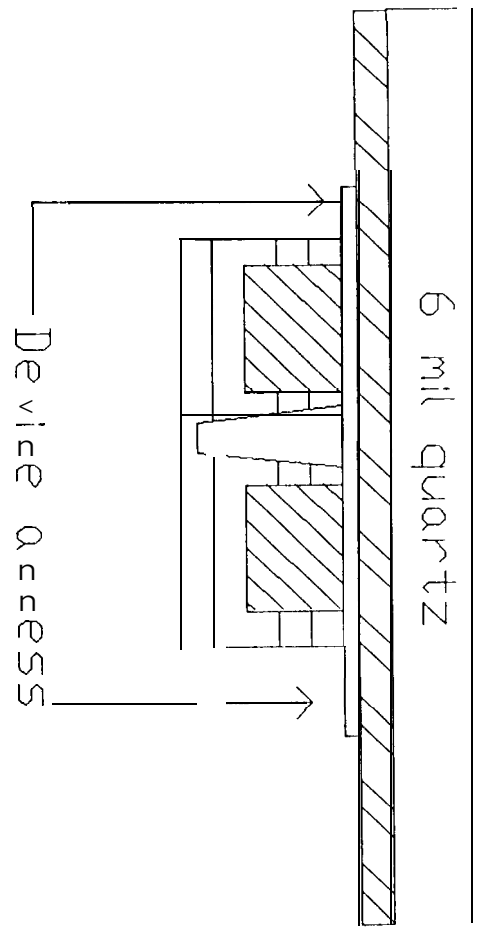
(e) Surface Channel Etch



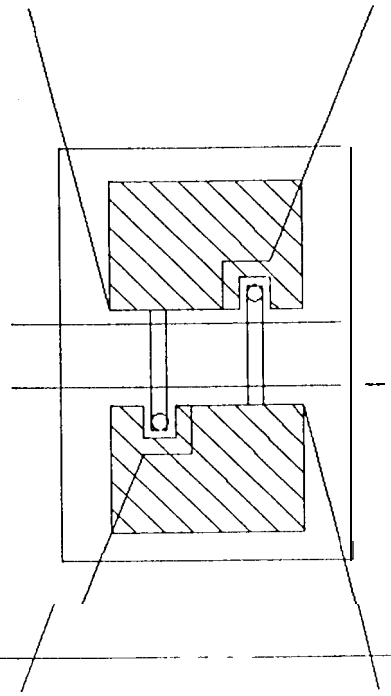
(f) Upside down mount

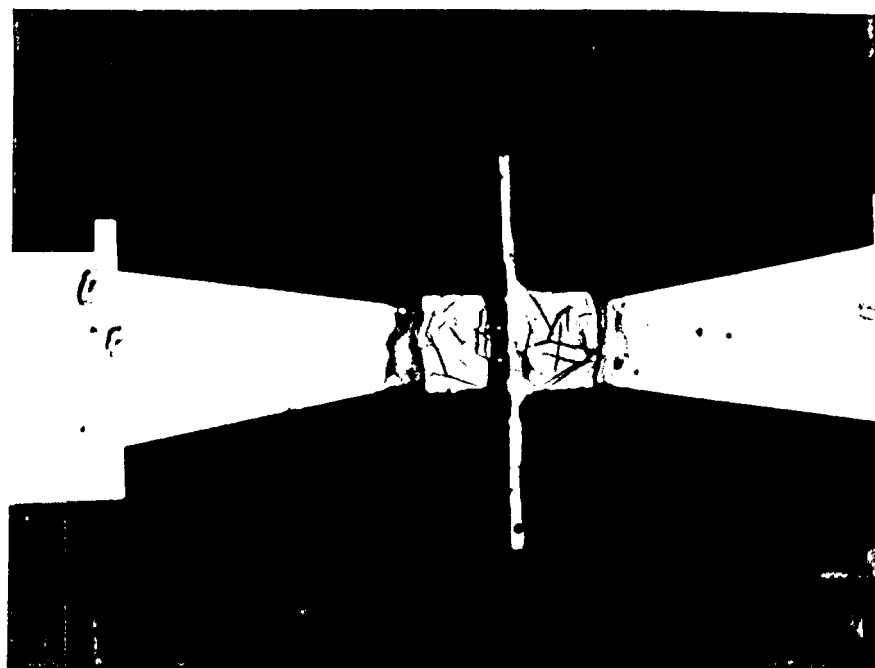


(g) Substrate removal

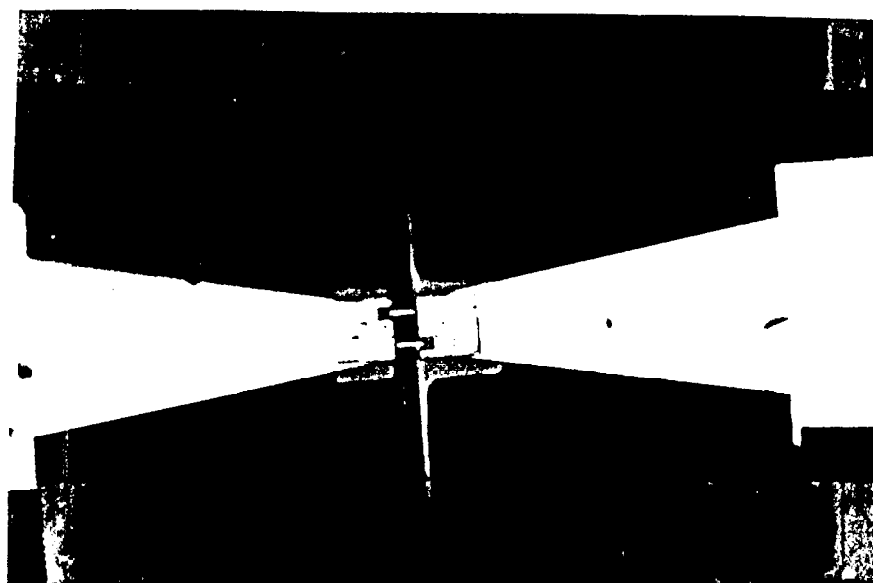


(h) Device isolation and etch





(a)



(b)

Fig 2: A back-to-back diode pair integrated with a filter structure, (a) the front side of the structure showing the GaAs pads over the Schottky diodes, (b) the bottom side (quartz) of the structure showing the fingers contacting the anodes.



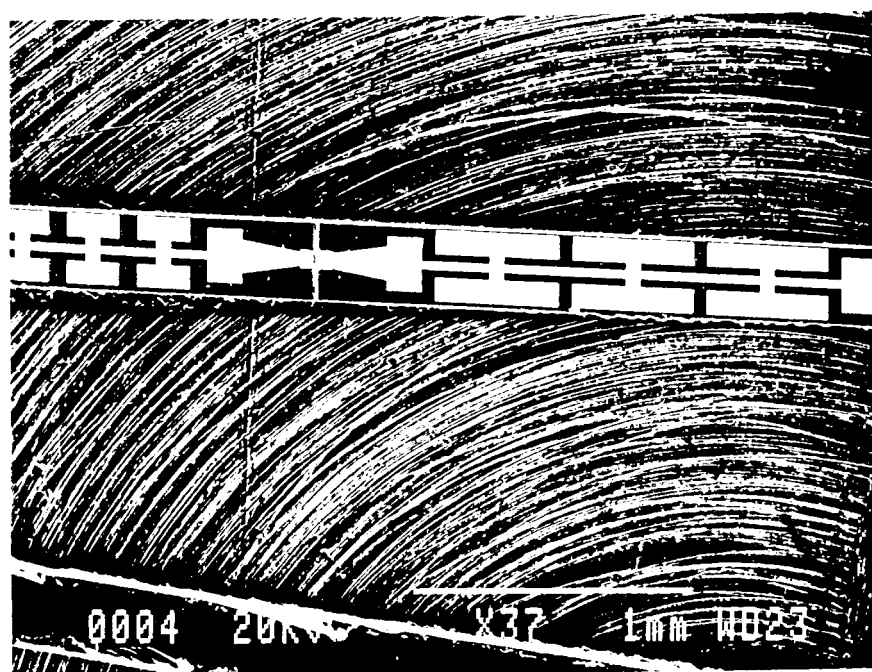


Fig 3. A portion of the mixer hammerhead filter and the planar back-to-back Schottky diode medullization side facing up. The structure is ready to be mounted , in a waveguide block.